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OPTICAL PARAMETRIC GENERATION OF GREATER THAN 30 mJ SIGNAL ENERGIES IN PPLN STACKS

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Optical parametric generation of greater than 30 mJ signal energies in PPLN stacks

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Coherent mid-infrared (IR) radiation sources with high pulse energies and good beam quality are needed for a variety of remote sensing applications. In this paper we report the generation of high-energy mid-IR pulses by pumping stacks of PPLN crystals with multiple elliptical beams in a single-pass optical parametric generator (OPG) configuration. Signal energies as high as 33 mJ in 3.5-ns pulses were achieved with bare (i.e., uncoated) PPLN crystals while maintaining excellent beam quality. To the best of our knowledge these are the highest mid-IR signal energies ever generated with nanosecond pulses in uncoated PPLN crystals, but this system should easily be scaleable to generate much higher signal energies.

The primary barrier to developing high-energy pulsed PPLN systems has been the large coercive field (~21 kV/mm) of lithium niobate, which has limited electric field poling of PPLN crystals to a maximum thickness of about 1 mm [1]. While not a problem for continuous-wave devices which typically focus the pump beam tightly to enhance nonlinear gain, this aperture limitation combined with the low damage fluence of lithium niobate (~3 J/cm^2 for nanosecond pulses) has restricted pulsed PPLN devices to low-energy operation. Recent efforts to overcome the aperture limitation in pulsed PPLN systems have included pumping with elliptical beams [2] and diffusion bonding stacks of PPLN crystals [3]. The elliptical pump configuration allowed higher energy operation than traditional pump geometries, but the signal output suffered severe beam quality degradation and spectral broadening. In addition, diffusion bonding PPLN crystals (and stacking crystals with other methods) successfully increased the crystal aperture, but the seams between crystals often led to pump beam corruption and crystal damage at low pump energies. Thus, although these endeavors were positive steps in the quest for high-energy devices, they achieved neither the signal energies nor beam quality desired for remote sensing applications.

To overcome these problems we developed a system where each crystal in a stack of segmented grating PPLN crystals would be simultaneously pumped by an elliptical beam. By pumping each crystal independently with a large aperture beam, we use the full aperture of each crystal without illuminating the seams between crystals. This allows us to avoid low-fluence crystal damage caused by pump beam corruption at the crystal seams. In addition, previous experiments have shown that segmenting the grating structure in elliptically pumped OPG devices reduces the beam degradation and spectral broadening caused by the large aperture pump beam [4]. Thus, PPLN crystals with segmented gratings were chosen to make up the stacks.

For our experiments we used standard electric field poling techniques to fabricate eight 0.5-mm x 10-mm x 25-mm (thickness x width x length) segmented multi-grating crystals and stacked them to form a single 4-mm thick by 10-mm wide crystal stack. Each crystal had 25 grating periods ranging from 25-μm to 31.25-μm in 0.25-μm increments. The individual gratings were 400 μm wide and separated by 50 μm. We have found in previous experiments that diffusion bonding multi-grating crystals causes severe internal strain in the crystal stack, so we simply used a high-temperature wax to bond the crystals together. The input and exit faces of the crystals were uncoated (i.e., bare lithium niobate) for our initial experiments, but we have plans to use high damage threshold coatings in the future.

The pump beam was supplied by a Coherent Infinity Q-switched Nd:YAG laser operating at 10 Hz with 3.5-ns pulses. The operating wavelength was 1.064 μm and the output from the laser was a tophat beam profile. We imaged and slightly magnified the tophat beam onto a cylindrical lens array to generate the multiple elliptical beams. The array was 7-mm x 7-mm (width x height) with 14 cylindrical lenslets separated by 0.5-mm center to center. The focal length of each lenslet was ~50 mm and the front and back surfaces of the array were antireflection coated for 1.064 μm. We then simply placed the crystal stack at the focal plane of the lens array to perform our experiments.

We used the setup described above to pump the PPLN stack in a single-pass OPG configuration with pump energies up to 130 mJ without crystal damage. The maximum signal output measured was 33 mJ at 130 mJ of pump energy. The idler output at this level was ~13.5 mJ. This corresponds to an overall conversion efficiency of ~36 percent. As shown in Figure 1, the near field signal consisted of eight segmented elliptical beams which overlapped to form a single far field beam. The M^2 values were measured in the range of 1.5 to 1.9 (depending on pump energy and crystal alignment) for a pump M^2 of 1.2.

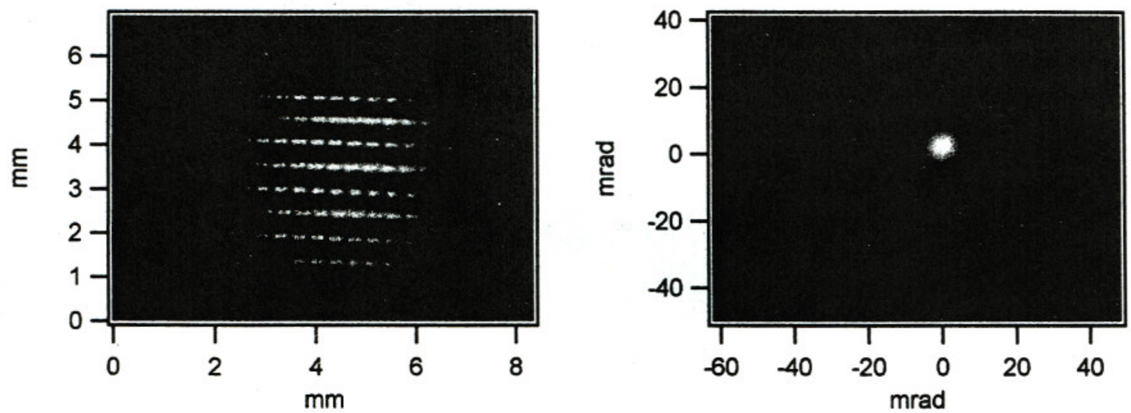

Figure 1 - Images of the near field (left) and far field (right) signal beams generated with the PPLN stack.

Multiple signal wavelengths were desired for our particular application, so we chose to fabricate our PPLN stack from segmented multi-grating crystals instead of segmented single-grating crystals. Each of the eight multi-grating crystals was fabricated with the same 25 grating periods, so the stack produced only the 17 spectral bands shown in Figure 2 (not all gratings were illuminated, thus there are not 25 bands). However, by simply stacking crystals with different grating periods we could have generated up to 200 distinct spectral bands with only eight crystals. Conversely, by making all gratings with the same period, it is possible to consolidate all of the signal energy into a single spectral band. We have verified this technique in individual segmented single-grating crystals and plan to perform experiments with stacks of these crystals in the near future.

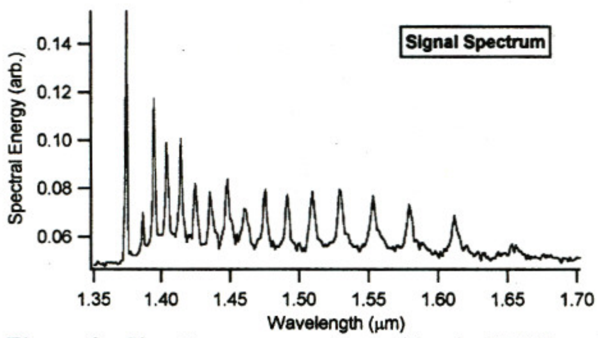

Figure 2 - Signal spectrum generated by the PPLN stack.

Although the 33 mJ of signal energy is impressive, with some simple modifications this system should be scaleable to much higher energies. For example, previous experiments have shown that coating the surfaces of PPLN crystals with SiO_2 can increase their damage threshold by a factor of 3.5 [4]. If we generate similar improvements by coating the crystals of our stack, signal energies on the order of 100 mJ would be possible. In addition, we chose to fabricate stacks of eight crystals, but more crystals could easily be added to the stack without degrading beam quality.

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